Geochemistry and the Distribution of Uranium and Thorium in the Granitoid Rocks of the South Mountain Batholith, Nova Scotia: Some Genetic and Exploration Implications

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Nova Scotia

Department of
Mines and Energy

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GEOCHEMISTRY AND THE DISTRIBUTION OF URANIUM AND THORIUM IN THE GRANITOID ROCKS OF THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA: SOME GENETIC AND EXPLORATION IMPLICATIONS

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Abstract

The peraluminous South Mountain Batholith (SMB) of Nova Scotia consists of a cogenetic granitoid suite ranging in composition from biotite granodiorites to highly leucocratic monzogranites. Economically significant U-Sn prospects and numerous occurrences show a close spatial and genetic association with the more highly differentiated phases of the SMB, and in particular with a paraintrusive suite developed in these bodies. In the cogenetic suite uranium concentrations increase progressively with differentiation, but thorium follows two distinct trends. Thorium concentrations and Th/U ratios decrease with differentiation in the New Ross complex, and the Lake George, East Dalhousie and West Dalhousie plutons. However, in the Davis Lake and Plymouth plutons thorium values increase concomitantly with uranium enrichment. Airborne gamma ray spectrometric maps have been used to distinguish areas of high total radioactivity (i.e. highly differentiated) and high thorium values within the batholith. Such areas correspond to bodies showing the thorium-enrichment trend and are concentrated near the margins of the batholith. Major U-Sn occurrences in the batholith appear to be preferentially associated with these bodies and airborne gamma ray spectrometric surveys provide information on the location of such bodies in less well known parts of the batholith. The strong enrichment of elements such as Li, Be, F, Rb, Cs, U, and Sn in members of the paraintrusive suite provides another possible lithogeochemical exploration tool.

Résumé

Le batholite peralumineux de South Mountain (BSM) de la Nouvelle-Ecosse est formé d'une série de granitoïdes co-génétiques dont la composition varie des granodiorites à biotite aux monzogranites fortement leucocrates. Des gisements d'U-Sn ayant un potentiel économique ainsi que de nombreux autres indices de métaux indiquent une association spatiale et génétique proche avec les phases les plus différenciées du BSM et en particulier avec une série para-intrusive qui s'est développée dans ces masses. Dans la série co-génétique, les concentrations d'uranium augmentent progressivement avec la différenciation, mais le thorium suit deux tendances distinctes. Les concentrations de thorium et les rapports Th/U diminuent avec la différenciation dans le complexe de New Ross, le pluton du Lac George, celui de Dalhousie Est et celui de Dalhousie Ouest. Cependant, dans les plutons de Davis Lake et de Plymouth, les valeurs du thorium augmentent parallèlement à l'enrichissement en uranium. Des cartes de spectrométrie aérienne des rayons gamma ont été utilisées pour distinguer les zones de radioactivité totale élevée (c'est-à-dire fortement différenciées) et les valeurs élevées en thorium dans le batholite. Ces régions correspondent aux masses montrant la tendance à l'enrichissement en thorium et sont concentrées près des marges du batholithe. Les indices importants d'U-Sn dans le batholithe semblent être associés de préférence à ces masses et les levés spectrométriques aériens des rayons gamma donnent des renseignements sur l'emplacement de tels masses dans les parties les moins bien connues du batholithe. Les forts enrichissements en éléments comme Li, Be, F, Rb, Cs, U et Sn dans les membres de la série para-intrusive fournissent un autre instrument d'exploration lithogéochimique possible.

Introduction

The South Mountain Batholith (SMB) is a posttectonic, peraluminous granodiorite-granite complex which outcrops over an area $>10^4$ km^2 of southwestern Nova Scotia (Fig. 2.1) and is one of the largest batholiths in the Appalachian geological province. During the past decade the SMB has been the site of increasingly intense mineral exploration which has culminated recently in the discovery of a major Sn (East Kemptville, Shell Minerals Ltd.) and a major U (Millet Brook, Aquitaine Mining Corp.) prospect, as well as numerous other showings of these metals (Fig. 2.1).

The SMB mainly intrudes deformed metawackes and metapelites of the Cambro-Ordovician Meguma Group, but along its northwestern margin it cuts metasediments and volcanics ranging in age from Ordovician to Lower Devonian (Emsian). Country rock deformation and metamorphism is attributed to the Acadian Orogeny, which in this region has been dated at 415-400 Ma (Reynolds and Muecke, 1978). Clastic sediments of Tournaisian age are found resting unconformably on eroded SMB. These stratigraphic controls necessitate that the intrusion, crystallization, uplift and erosion of the batholith be bracketed betwen Emsian and

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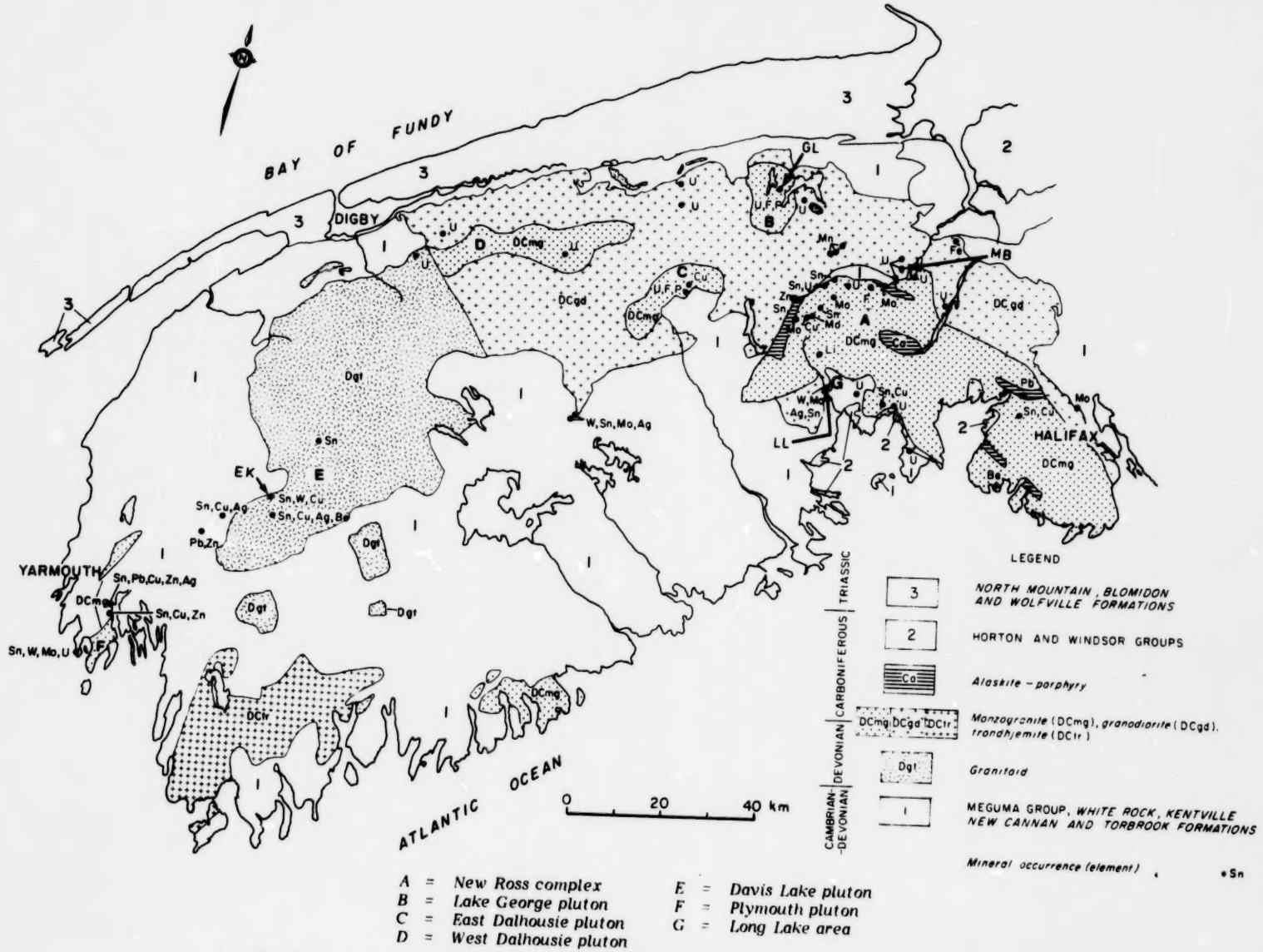

Specific occurrences mentioned: Millet Brook (MB), Lewis Lake (LL), East Kemptville (EK), Gaspereau Lake (GL).

Figure 2.1. *Geological map of southern Nova Scotia showing the extent of the South Mountain Batholith and the distribution of major rock types. All known occurrences and prospects of U and Sn within, or closely associated to, the granitoid rocks are indicated.*

Tournaisian times. Recent Rb-Sr isochron ages of 372-361 Ma are assigned by Clarke and Halliday (1980) to the various episodes of intrusion in the batholith. K-Ar and $^{40}Ar/^{39}Ar$ studies by Reynolds et al. (1981) gave a mean age of 367 Ma for the batholith, in good agreement with the Rb-Sr ages. The intrusive episode therefore straddles the Devonian-Carboniferous boundary and the time span between complete solidification and surface exposure of parts of the SMB cannot have been more than a few million years. Such rapid unroofing of the batholith during (?) and following its emplacement has had a profound effect upon the localization of associated mineralization.

Petrology and Geochemistry

The main mass of the SMB consists of biotite granodiorites into which are intruded a number of smaller, discrete bodies of biotite-muscovite monzogranites (including porphyry), leucocratic monzogranites, dykes and irregular bodies of aplite and pegmatite (Fig. 2.1). Geochemically this suite varies in Thornton-Tuttle differentiation index from about 75-95 and contains 1-3 per cent normative corundum (McKenzie and Carke, 1975). The major and many trace elements of this suite show continuous variation trends from the early to late-stage rocks. From this, McKenzie and Clarke (1975) concluded that the SMB consists of a cogenetic suite whose chemical trends were controlled by fractional crystallization involving mainly plagioclase and biotite. Recent age determinations and Sr isotope studies strongly support such a cogenetic model. Although most large ion lithophile elements, especially Rb and Cs, show a predictable increase in abundance with increasing degree of differentiation some, such as the rare earth elements (REE), show a regular, but unexpected, decrease. Muecke and Clarke (1981) concluded from the REE and Sr isotope data that fractional crystallization alone cannot account for the trace element geochemistry of the late-stage rocks. They suggest that three processes, namely fractional crystallization, country rock assimilation, and fluid phase transfer, have all operated during the crystallization history of the SMB. The generation of a fluid phase, possibly enriched in fluorine, is thought to have played a major role in determining geochemical trends during the terminal phases of crystallization. The presence of such a fluid would also have had a profound influence on the behaviour of such economically important elements as Sn and U, since they can form stable fluoride complexes in aqueous solutions.

A paraintrusive suite, which consists of biotite leucogranites, argillized and sericitized granites, albitized granites and albitites, as well as various types of greisen, appears to be the product of the interaction of such a fluid phase with residual magma and/or the cogenetic crystalline rocks. The principal Sn-W, Sn-Be, Sn-W-U, W-Mo-U, and U-P-F mineralization in the SMB is usually spatially and genetically associated with the monzogranite and leucocratic monzogranite bodies, and in particular with paraintrusive rocks found within these complexes (Fig. 2.1).

Mineralization

The principal types of U and Sn mineralization so far recognized in the SMB are typified by the following:

i) In the New Ross area uraniferous shear zones occur in granodiorites at Millet Brook, in leuco-monzogranite at Lewis Lake, and at many other localities within the greisen zones. The shear zones show distinct evidence of cataclasis and generally trend northerly with varying dips. The uraniferous shear zones are usually characterized by strong alteration which includes hematization, muscovitization, albitization and in some cases silicification. The mineralized shear zones are characterized by autunite – torbernite – pitchblende associations and the gangue minerals may include calcite, quartz, hematite, pyrite, chalcopyrite, apatite, Li-micas, and albite.

ii) The uranium mineralization at Gaspereau Lake is restricted to an easterly dipping shear zone in leuco-monzogranite. The mineralization is characterized by autunite – meta-autunite – torbernite associated with hydroxyl – and fluor-apatites. Phosphatization, muscovitization and hematization of the wall rocks are typical alteration features. The style and geological setting of the mineralization at East Dalhousie is essentially similar to the Gaspereau Lake prospect. However, the shearing is more pronounced at East Dalhousie and uraniferous shear zones have a sheeted vein appearance. Also, albitization of the wall rocks is more intense and pitchblende is found in addition to uranium phosphate minerals.

iii) The Sn-W-Cu ± Mo mineralization at Davis Lake, Plymouth, and Long Lake is restricted to greisen zones and greisenized granites within discrete bodies (?) of leuco-monzogranite. The dominant polymetallic mineralization at these localities is found mostly as disseminations and as quartz-topaz-cassiterite-sulphide veins. The greisen zones and the veins range in width from hairline fractures to tens of metres. Diagnostic alteration associated with the mineralization includes fluoritization, muscovitization and albitization.

Sampling and Analytical Techniques

In the course of this project both surface and drill core samples were analyzed for major and trace constituents. Surface samples were carefully selected to include only the least weathered material and generally came from road cuts or trenches. No systematic differences could be detected between U or Th/U values obtained from outcrop samples and those from drill cores. An exception to this observation is one drill core from the New Ross area in which U is strongly depleted in the upper 100 m of core. We do not believe that this depletion is a surficial phenomenon but think that it stems from late-stage hydrothermal interaction.

U and Th were determined by instrumental neutron activation analysis (INAA) and delayed neutron activation analysis (DNAA). Other trace elements referred to in the text were determined by INAA (REE, Cs, Ta, Sc, Hf), atomic absorption spectrometry (Li) and X-ray fluorescence analysis (Rb, Ba, Sr, Ti, Zr, Sn).

Uranium-thorium distributions

In the cogenetic suite the mean U and Th abundances (3.9 ppm and 11.5 ppm, respectively) of the biotite granodiorites fall close to those postulated for average continental crust and the global average for granodioritic rocks (3 ppm, 10 ppm; Taylor, 1966). With increased degree of differentiation (using Thornton-Tuttle index) the mean U content rises to 6.1 ppm in the monzogranites and 8.3 ppm in the leuco-monzogranites for rocks from the New Ross, Lake George, East Dalhousie, and West Dalhousie plutons (Fig. 2.2). Thorium, on the other hand, decreases in abundance and mean Th/U ratios change from 3 in the granodiorites to 0.5 in the leuco-monzogranites (Fig. 2.3).

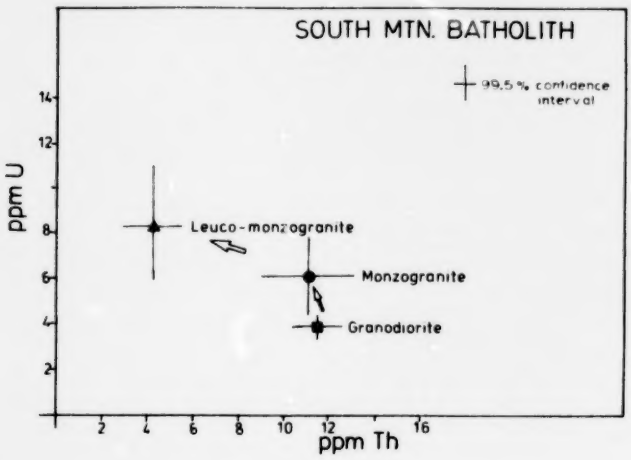

Figure 2.2

Th-U variation diagram showing means of major rock types of the cogenetic South Mountain Batholith suite and 99.5% confidence intervals on the means. Data for the monzogranites and leuco-monzogranites include the New Ross complex, Lake George pluton, East Dalhousie pluton, and West Dalhousie pluton.

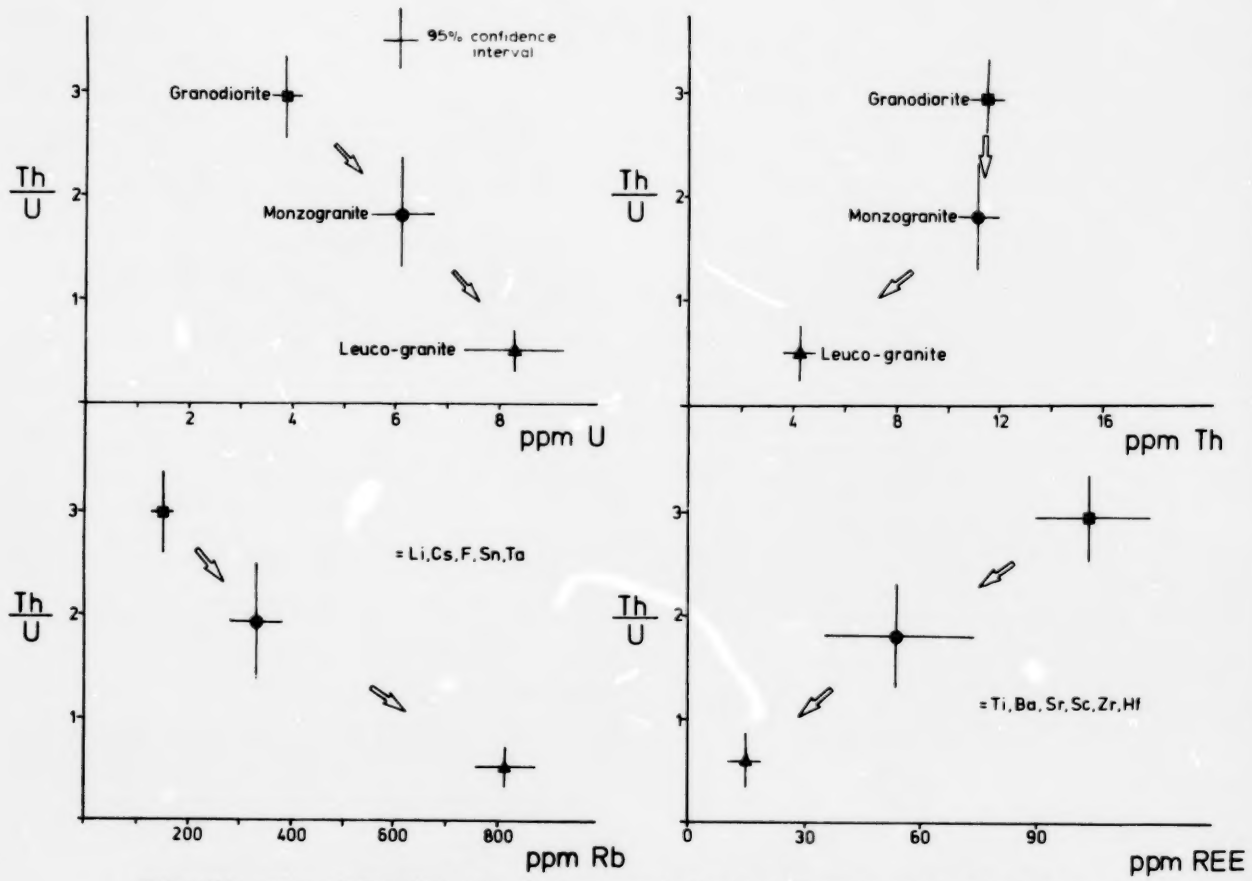

Figure 2.3. *Mean Th/U ratios of rock types constituting the cogenetic suite plotted against U and Th. Also shown are correlations with other trace elements. Note that REE, Ba, Sr, Ti, Sc, Zr, and Hf decrease with decreasing Th/U ratio (increased differentiation) in a manner similar to Th. Li, Rb, Cs, F, Sn, and Ta increase with decreasing Th/U, as does U. Data base same as Figure 2.2.*

Such a decrease in Th and Th/U (also of REE) is most unusual for a differentiated intrusive suite. The decrease in Th/U with differentiation is accompanied by strong progressive enrichments in F, Be, Li, Rb, Cs, Ta, Sn, and U, and depletions in Sr, Ba, REE, Sc, Zr and Hf (Fig. 2.3).

In the paraintrusive suite the elemental correlations described above often break down as particular elements may show extreme enrichments (e.g. U, Sn, Li) or depletions (e.g. REE, Th). For example, in some greisen zones REE values have been found to be depleted by a factor of up to 50 relative to host monzogranites, whereas Li enrichment commonly exceeds a factor of 10 (Charest, 1976). Thorium levels remain low during the alteration process.

The negative correlation between Th and U and the Th depletion with increasing differentiation (Fig. 2.2) which we have observed for most of the plutons is, however, not shared by all plutons in the SMB or those associated with it. Notable exceptions are the Davis Lake and Plymouth plutons which show a positive correlation between U and Th and elevated Th abundances in the most differentiated rocks and the paraintrusive suite (Fig. 2.4); both bodies are associated with substantial Sn-W mineralization.

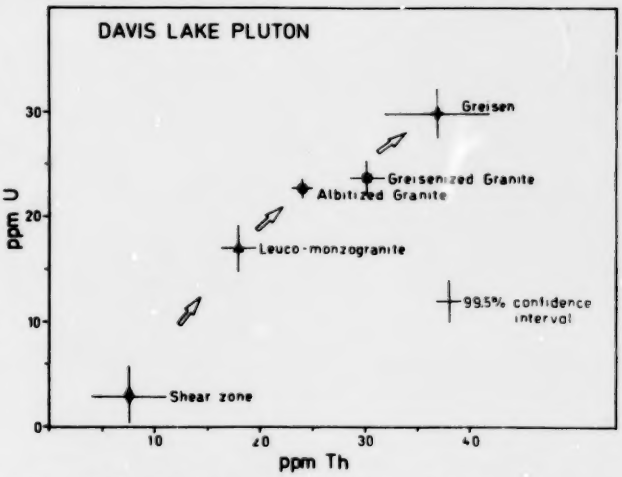

Figure 2.4. *Th-U variation diagram showing means of major rock types from the Davis Lake pluton. Note positive correlation between Th and U in contrast to trends observed in most plutons within the SMB (Fig. 2.2).*

Exploration Implications

From the above discussion it appears that two distinct geochemical trends can be discerned in the plutons which constitute the SMB: i) a Th-depletion (also REE depletion) trend in which increased igneous differentiation leads to low Th and low Th/U, both in the cogenetic and paraintrusive suites; and ii) a Th-enrichment trend in which highly differentiated rocks and paraintrusives are characterized by a concomitant increase in Th and U.

Airborne gamma ray spectrometric maps with 5 km line spacing flown in an E-W direction are available over the area of the SMB for total count (Ur), eK, eU and eTh (Geol. Surv. Can., 1977). We have analyzed these in an attempt to delimit the locations of bodies which display the above geochemical trends. In general, the areas of high total count (taken as >10 Ur; Fig. 2.5) conform to the major bodies of monzogranite and more highly differentiated rocks (e.g. New Ross complex, Davis Lake pluton). In some cases these more highly radioactive bodies show low Th counts (e.g. New Ross complex) in accord with the Th-depletion trend observed in ground sampling (Fig. 2.2, 2.5). The low Th content of Lake George and East Dalhousie monzogranites has apparently depressed the total count below our chosen threshold and contributed to the lack of strong total count anomalies over these bodies and confirms their affinity with the Th-depletion trend. In other cases, the high total count value is accompanied by a high Th count (>6 ppm eTh) and confirms the Th-enrichment trend observed in ground samples (e.g. Davis Lake). Superposition of the high total count (>10 Ur) and high Th (>6 ppm eTh) areas yields an interesting areal distribution (Fig. 2.5). High Th and high total count areas within the SMB show a well developed zonal distribution and lie near the margins of the batholith. Furthermore, a comparison of Figures 2.1 and 2.5 shows a close correlation between such areas and major mineral occurrences (i.e. Plymouth and Davis Lake plutons with Sn prospects; Millet Brook U prospect) which may be of exploration interest. This approach suggests that bodies in the SMB which show the Th-enrichment trend may be more favourable areas for Sn-U mineralization than those showing the Th-depletion trend. Using these criteria other areas in sparsely mapped portions of the SMB stand out as possible exploration targets, such as an oblong area south of West Dalhousie pluton along the southern margin of the batholith and an oval area west of Lake George pluton.

Other possible lithogeochemical indicators of Sn-U mineralization in the SMB are the strong enrichments of F, Be, Li, Rb, Cs, Ta, Sn and U encountered in the associated paraintrusive suite. From the available data it appears that the strongest Li enrichment is associated with those bodies showing predominant U mineralization (Fig. 2.6). Furthermore, a preliminary study of REE in fluorites from Sn-U mineralized and apparently barren areas (Muecke and Clarke, 1981) has shown that fluorites in the former have elevated REE concentrations and may prove to be guides to mineralization. Relative REE distributions in all the fluorites closely resemble those observed in the leucomonzogranites and reflect the close genetic link between the highly differentiated, late crystallized fractions of the batholith and the evolution of the fluid phase which gave rise to the observed mineralization in the SMB.

Vertical profiles of U distributions in the New Ross area show that near-surface samples (<100 m) can be markedly deficient in uranium, but other areas (e.g. Davis Lake) do not exhibit such a trend. We suggest that such distribution patterns are the result of the interaction of differentiated granitoid rocks with heated meteoric and/or internally generated fluids. These released and concentrated U through oxidation and complex formation.

Conclusions

The South Mountain Batholith consists of a series of plutons which were emplaced into Lower Paleozoic metasediments 372-361 Ma ago. Compositions range from early crystallized biotite granodiorites to late stage leucomonzogranites, all of which are peraluminous and appear to be members of a cogenetic suite. Uranium always shows progressive enrichment with increased differentiation, but thorium follows two distinct trends. In the New Ross complex, Lake George, East Dalhousie and West Dalhousie

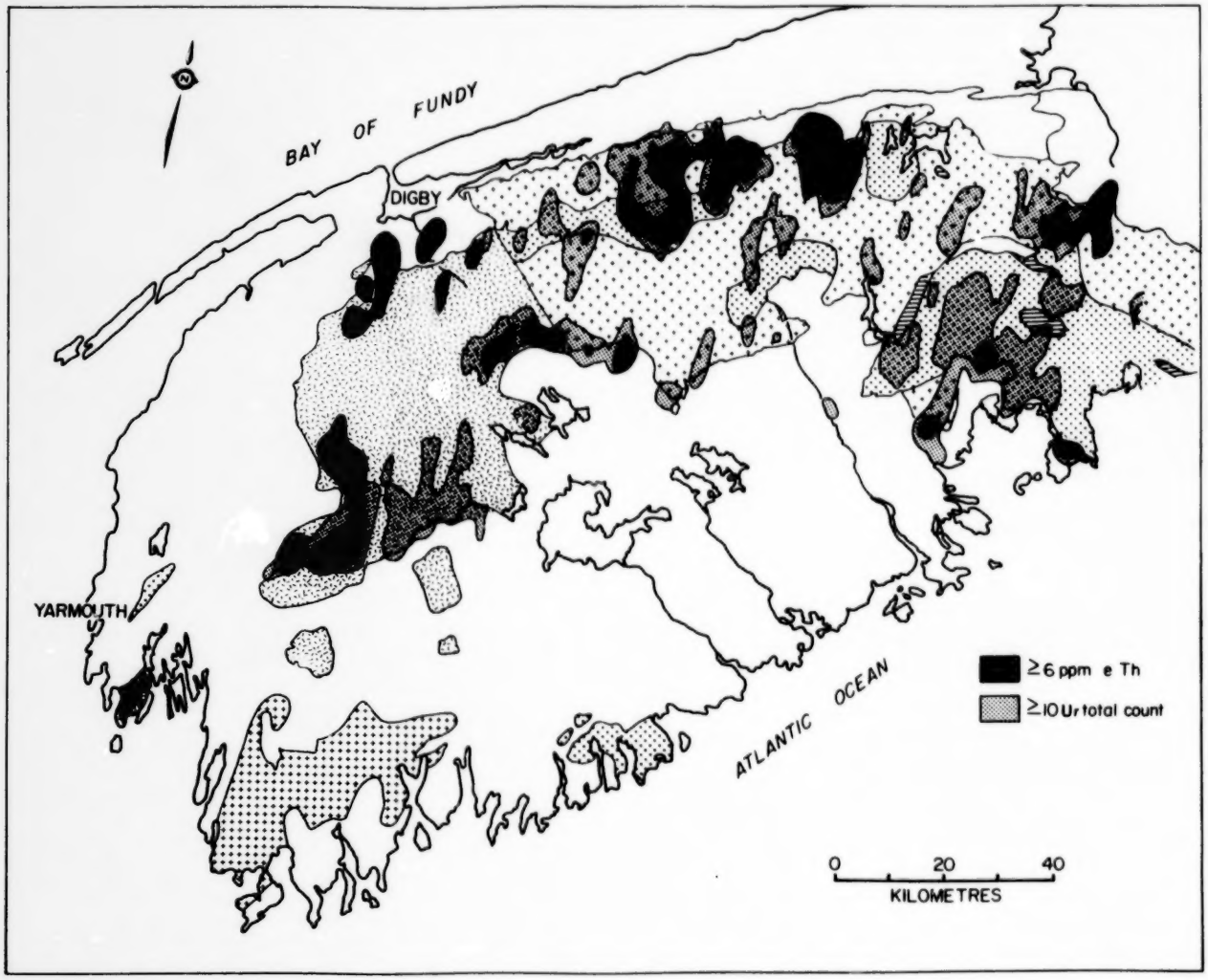

Figure 2.5 *(above). Map of southern Nova Scotia showing the correlation between areas of high total count (>10 Ur) and high thorium values (>6 ppm eTh), obtained from airborne gamma ray spectrometric maps (Geol. Surv. Can., 1977), and bedrock geology. Note the occurrence of high total count plus high thorium areas near the margins of the batholith. Lithologic symbols as in Figure 2.1.*

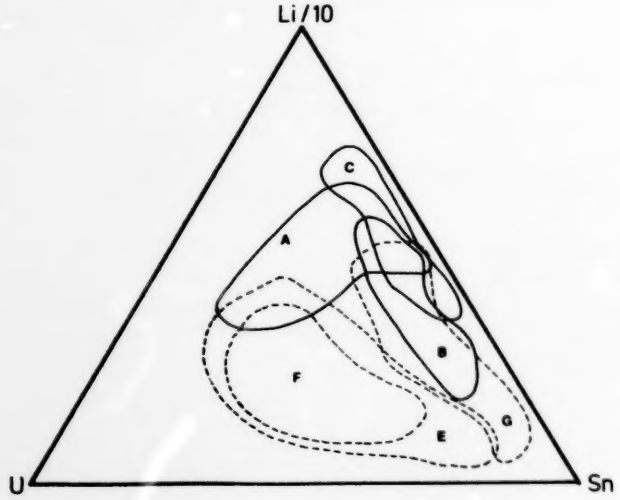

Figure 2.6. *Ternary variations diagram of Li-U-Sn for subdivisions of the South Mountain Batholith. The New Ross complex (A), Lake George pluton (B), and East Dalhousie pluton (C) are mainly associated with U mineralization and tend to show higher Li concentrations. The Davis Lake pluton (E), Plymouth pluton (F), and Long Lake area (G) are mainly associated with Sn mineralization and show lower Li concentrations.*

plutons, thorium decreases markedly with igneous differentiation, as does the Th/U ratio. On the other hand, in the Davis Lake and Plymouth plutons Th increases concomitantly with U. The paraintrusive rocks which are associated with the Th-depletion trend show the same trends as those observed in their cogenetic precursors; it has yet to be determined whether a similar relationship exists for the Th-enrichment trend. In the paraintrusive equivalents the elemental correlations observed in the cogenetic suite are, however, frequently obliterated by extreme enrichments or depletions of certain elements. Airborne gamma ray spectrometric maps can be used to identify areas in the SMB which exhibit the Th-enrichment or Th-depletion trends. Thorium-enriched areas show a strikingly consistent areal distribution and are located near the margins of the SMB. Major known occurrences of Sn and U appear to be spatially associated with the Th-enriched bodies and this correlation provides a criterion for favourable future exploration targets. The close association of the mineralization with the paraintrusive suite and characteristic strong elemental enrichments, particularly of Be, F, Li and Rb, provide further lithogeochemical guides to mineralization.

The localization of U mineralization along shear zones in the SMB suggests that the rapid unroofing of the batholith following its emplacement produced dilatancy and shear fractures which acted as channelways for mineralizing fluids which were produced as internally generated fluids or by the interaction of the differentiated granitoid rocks with hot meteoric water. Uranium concentrations of economic interest in the SMB are, therefore, the cumulative result of igneous differentiation processes and a hydrothermal system which acted on the cooling batholith during an episode of rapid uplift.

Acknowledgments

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